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SEDIMENT FLUXES AND PARTICLE GRAIN-SIZE CHARACTERISTICS OF WIND-ERODED SEDIMENTS IN SOUTHEASTERN AUSTRALIA

JOHN F. LEYS

Conservation and Land Management, P.O. Box 462, Gunnedah, N.S.W. 2380 Australia

GRANT H. MCTAINSH

Griffith University, Nathan, Queensland 4111, Australia

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ABSTRACT

Grain-size characteristics and the flux of sediment transported by wind from a cultivated paddock in a Quaternary relict dune field are described. Sediments were collected at seven heights between 0·7 and 2·0 m. The distribution of sediment mass with height is explained by a power function (of the order of -1), which is highly skewed towards the bed. The distribution of $< 90\ \mu$m sediment mass is explained by a log function of height and is less skewed towards the bed because these finer particles are influenced by the vertical velocity component of the wind. The particle-size distribution (PSD) of the eroded sediments is strongly influenced by the PSD of the parent material. Enrichment of the suspended sediment (PSA $< 90\ \mu$m) was in the order of 2·3 times. Sediment flux measurements show that 93 per cent of the erosion occurred in 3 per cent of the time.

KEY WORDS wind erosion, aeolian soil, aeolian sediments, particle size characteristics, sediment flux

INTRODUCTION

Wind erosion in Australia often produces dust plumes that travel great distances. McTainsh (1989) reported that at least seven accounts of dust transport to New Zealand have been published this century, and the meteorological records of dust hazes show that there have been many more large-scale wind erosion events.

An understanding of the erosion process and in particular the quality and quantity of dust being removed from a paddock (field) is required if sound land management recommendations are to be made. Wind erosion processes can be subtle in their removal of soil and nutrients from a paddock. The winnowing of soil fines and organic matter from the soil results in the removal of small masses of highly nutrient-enriched sediment. The removal of this enriched sediment reduces the productivity of the sandy soils in the semi-arid farming zone of southeast Australia.

The finer suspended particles can be carried great distances, and will be removed from a paddock. For example, Raupach (1993) reports that 90 μm particles travel approximately 5 km, 10 μm particles travel 400 km and 1 μm particles travel >1000 km if initial wind conditions are strong enough to mix the dust through the entire depth of the convective boundary layer. This is also consistent with Gillette's (1977) assertion that the loss of fines may permanently decrease the nutrient and water-holding capacity of the eroded soil.

In Australia, dust storms consist of suspended sediment ejected from eroding paddocks during wind

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erosion events. Paddock scale measurements of streamwise sediment flux have been made in rangelands (Miles, 1993) but not on cultivated land. The introduction of suitable portable sediment samplers for the measurement of wind erosion by Fryrear (1986) and their subsequent modification by McTainsh and calibration by Shao *et al.* (1993a) mean that such sampling is now possible.

Previous research has indicated that various factors affect the quantity and quality of suspended sediment. Increasing wind speed was shown to increase the proportions of fines removed from the soil as well as the total mass of soil moved (Chepil, 1957; Gillette, 1977). Earlier work (Chepil and Woodruff, 1957; Goossens, 1985) showed that the mean grain size, and the mode (Gillette, 1977; Nickling, 1983) of suspended sediment decreased with height. Gillette and Walker (1977) described the particle size of the soil and sediments from a range of heights and showed that the size distribution of eroded sediment close to the ground strongly reflects the size distribution of loose material in the parent soil. Nickling (1983) described the particle-size distribution (PSD) of the soil, creep, saltation and suspended fractions to show how both the PSD and mass of sediment decrease as a power function with height. Goossens (1985) undertook similar particle-size work to Nickling except that his data are based on deposition samples caught in buckets for various heights, while Nickling used active traps that filtered the airflow. These power functions have been further supported with more recent work by Goossens (1985) and Zoebeck and Fryrear (1986).

This is the first in a series of papers that will look at the wind erosion processes at both paddock and plot scale at Mendook. This paper describes the distribution of sediment mass with height, the particle-size characteristics of these sediments, their relationship to the soil, and sediment flux rates. Future papers will describe nutrient discharge from the paddock, the relationship between nutrients and particle size and the role of wind profile conditions in sediment transport.

MATERIALS AND METHODS

The study area was a 280 ha cultivated paddock on Mendook Station, in southwest New South Wales (lat. 34°30′S, long. 142°45′E). The test paddock was rectangular in shape, being 3·5 km long and 1 km wide. The paddock was orientated with its long axis from southwest to northeast. The test paddock was surrounded by non-eroding paddocks for 3 km and, therefore, all eroded sediments are assumed to be from within this paddock.

The sediment samplers were located 500 m from the northwestern and southeastern edge, 2000 m from the southwestern edge and 800 m from the northeastern edge of the paddock. The samplers were located on a sandy dune rise within undulating terrain (maximum relief 17·5 m), which is part of a relict dunefield (Bowler and Magee, 1978) that was probably formed during the last major arid phase (18 000 BP). Slopes are in the order of 1·5 per cent to windward (southwest) and leeward of the sediment samplers. The soils are predominantly deep siliceous sands (Stace *et al.*, 1968) of sand and loamy sand surface texture. The top 1 cm of soil was sampled next to the sediment sampling towers.

High-resolution particle-size analyses were performed in the Griffith University Particle-Sizing Laboratory using a Coulter Multisizer (256 size class intervals) in the range 2 to 75 μm, with dry sieving >75 μm at $\frac{1}{4}\phi$ intervals. The < 2 μm fraction was measured with pipette. FeO and organic matter were removed from the soils and sediments prior to an overnight dispersion in 1 M NaOH and 10 per cent Calgon (trisodium hexametaphosphate). Particle-size data are expressed at $\frac{1}{4}\phi$ intervals (38 size classes).

Sediment was sampled at heights (z) of 0·07, 0·12, 0·25, 0·5, 1·0, 1·5 and 2·0 m with modified Fryrear sediment samplers described by Shao *et al.* (1993a). The sampler orientates into the wind, has a intake with dimensions of 50 mm by 20 mm and has a sampling efficiency of 90 ± 5 per cent for the soil type at this site (Shao *et al.*, 1993a). Sediment samples were collected weekly for 22 weeks beginning on 15 October 1990. Samples were washed from the trap collection tray of the sampler then dried at 60°C for 72 h before weighing. The average wind speed (u_z) was measured with cup anemometers at four heights, $z = 0{\cdot}5$, 1·0, 2·0 and 4·0 m. Average wind direction was measured at 4 m height. Wind data were collected every 6 s and averaged over 12 min periods.

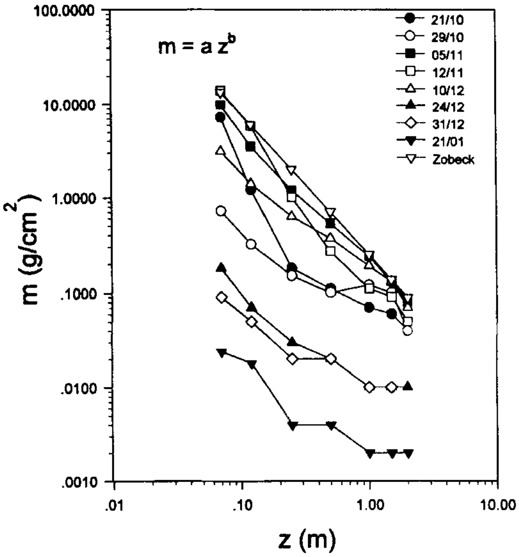

Figure 1. The mass of sediment collected ($g\,cm^{-2}$) at seven heights for eight different sampling periods at Mendook and data from a single storm on 25 July 1984 as described in Zobeck and Fryrear (1986) (denoted as Zobeck)

RESULTS AND DISCUSSION

Distribution of soil mass with height

The mass of sediment trapped at seven heights for eight different sampling periods is given in Figure 1. The best relationship between height (within the limits of the data $z = 0{\cdot}07$ and 2 m) and mass of sediment is

$$m = \alpha z^{-\beta} \tag{1}$$

where m = mass of sediment collected through a $10\,cm^2$ orifice (in $g\,cm^{-2}$), z = sample height, and α and β = regression coefficients. Results are given in Table I for eight weeks that cover the range of erosion events. The exponent β describes the decrease in the mass of sediment with height (Goossens, 1985). This exponent varied between weeks and became increasingly small as weekly sediment fluxes increased. The coefficient α characterizes the density of suspended sediment and increases with weekly sediment flux (Q). Caution should be exercised with using Equation 1 beyond the measured height limits.

Table I. Equation statistics for equation of the form $m = \alpha z^{\beta}$ where m = mass of sediment collected ($g\,cm^{-2}$) at height z (m) for data for eight weeks from Mendook

Day/ month	Regression statistics			
	α	β	r^2	$P<$
21/10	0·072	−1·390	0·88	0·002
29/10	0·087	−0·655	0·86	0·003
5/11	0·217	−1·362	0·99	0·001
12/11	0·131	−1·682	0·98	0·001
10/12	0·171	−1·043	0·99	0·001
24/12	0·012	−0·908	0·97	0·001
31/12	0·007	−0·915	0·96	0·001
21/1	0·002	−0·781	0·89	0·001

Equation 1 implies that m approaches infinity as z approaches 0, but in the field Q reaches a maximum value dependent on wind conditions. Therefore, using Equation 1 to predict m at very low heights could lead to an overestimation. Nickling (1978) used the mean aerodynamic roughness length (z_0) as the lower limit where wind velocity is effectively reduced to zero. We use $z_0 = 0{\cdot}001$ m as determined by wind tunnel studies at the site.

A similar log–log expression for the relationship of sediment mass with height was reported by Nickling (1978), Goossens (1985) and Zobeck and Fryrear (1986). The curves from Mendook are compared in Figure 1 with that of a dust storm samples by Zobeck and Fryrear on 25 July 1984 (see their Table 2 for original data). The results are directly comparable because they used a similar sediment trap to the one used in this study. The intensity of the storms was greater in the study of Zobeck and Fryrear (1986). Their smallest event is equivalent to the largest event measured at Mendook.

The rapid decrease in sediment mass with height is a well documented feature of wind erosion which reflects the different particle sizes being transported and the turbulence of the wind flow. In this study, all the sediments collected in the sediment traps are assumed to have been transported by saltation and suspension processes. Material moving in saltation is either ejected from the bed by aerodynamic forces or dislodged by other saltating grains. This material quickly returns to the bed because its settling velocity (w_f) is much greater than the vertical velocity fluctuations (w') of the wind (Gillette, 1977). Material moving in suspension is ejected into the air flow by saltating grains (Shao *et al.*, 1993b), but remains aloft because w_f of the particles is less than w'. Saltation material tends, therefore, to be particles of greater mass which are transported close to the bed.

When the mass of the finer material (<90 μm) is considered, the distribution changes to a highly significant ($r^2 = 0{\cdot}99$, $P < 0{\cdot}001$) negative semi-log-linear relationship of the form

$$m < 90\,\mu m = 0{\cdot}16 + (-0{\cdot}31 \log(z)) \qquad (2)$$

where $m < 90\,\mu m$ = mass of material <90 μm (in g cm^{-2}) and z is height above the ground (in m) (Figure 2). The distribution of the fines is less skewed towards the bed because the fines are less affected by gravity and are more under the influence of the wind's turbulence. The distribution of fines with height is a reflection of the dispersion of the material away from the source under the influence of the vertical velocity fluctuations (w').

Particle-size characteristics of suspended sediments

Fine particle enrichment in dust. The PSDs of eight samples (soil plus seven sediment samples) from different heights ($z = 0{\cdot}07$, 0·12, 0·25, 0·5, 1·0, 1·5 and 2·0 m) are given in Figures 3a and b. As height

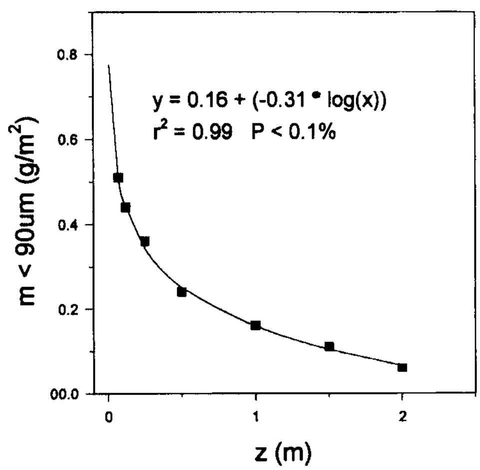

Figure 2. Distribution of mass of sediment <90 μm ($m < 90\,\mu m$) for seven heights (z) at Mendook

increases, sediment modal particle size becomes finer (Figure 3) and the percentage of fines (<90 μm) increases (Figure 4). As described previously, larger particles are transported at low heights because their settling velocities (w_f) are greater than the vertical velocity fluctuations of the wind (w'), where as for finer particles $w_f < w'$. Furthermore, as height increases, the probability of a finer particle being held aloft increases, causing enrichment of fine material with height (Gillette, 1977). Similar results have been reported by Chepil and Woodruff (1957), Nickling (1978, 1983), Goossens (1985), Zobeck and Fryrear (1986) and Gillette (1977), even though different particle-sizing techniques, and sometimes data presentation methods, were used.

The Coulter Multisizer technique used in this study, like most others, analyses the samples after dispersion in Calgon and following removal of iron oxides and organic matter. As a result, the particle-size distributions shown here will have higher clay percentages than the original undispersed samples, but from experimentation with different levels of dispersion, the shape of the PDSs >2 μm would change only slightly.

The distribution of percentage mass of sediment <90 μm with height (z) is best described by a positive semi-log-linear distribution of the form

$$\% < 90\,\mu m = 77{\cdot}0 + (47{\cdot}4 \log(z)) \tag{3}$$

with regression statistics of $r^2 = 0{\cdot}94$, $P < 0{\cdot}001$.

Figure 3 shows that at 0·07 m height 16 per cent of the material (by weight) is less than 90 μm, at 0·25 m there is 57 per cent <90 μm, and at 2 m there is 83 per cent <90 μm. This enrichment of the suspended sediments results in the depletion of fines from the surface soil which it was possible to quantify. The paddock at Mendook has been farmed for 30 years using disc ploughs, which invert the top 10 cm of soil, and tyned cultivators that mix the top soil. This has resulted in a relatively homogeneous PSD in the top 10 cm. In the year of the study, the paddock was worked once with a cultivator in September 1990. We

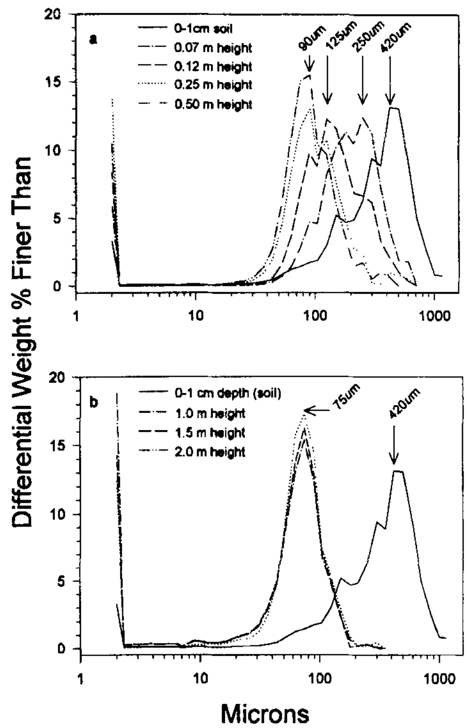

Figure 3. Particle-size distribution of the soil and seven eroded sediment samples for the week ending 10 December 1990 at Mendook: (a) soil (0–1 cm depth) and eroded sediments from heights $z = 0{\cdot}07$, $0{\cdot}12$, $0{\cdot}25$ and $0{\cdot}5$ m; (b) soil (0–1 cm depth) and eroded sediments from $z = 1{\cdot}0$, $1{\cdot}5$ and $2{\cdot}0$ m

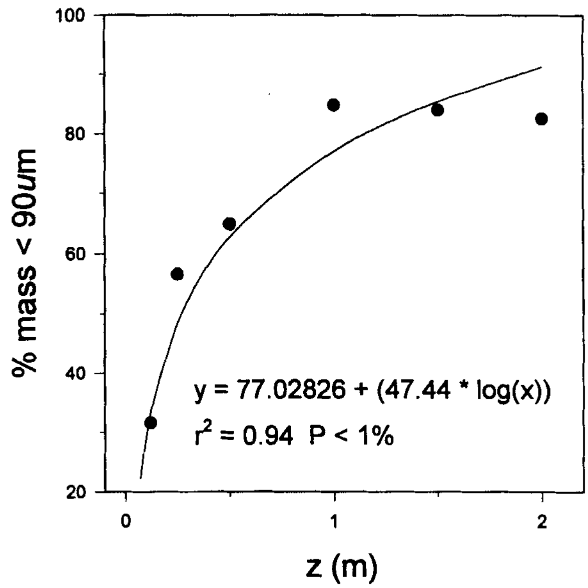

Figure 4. Relationship between percentage of sediment <90 μm (*% mass <90 μm*) for seven heights (*z*) at Mendook

assume a homogeneous PSD in the top 5 cm at the beginning of the study. Fifteen weeks into the study (25 February 1991) the soil was sampled at two depths (0–1 and 4–5 cm) and analysed for PSD. The results are given in Figure 5.

Figure 5 shows that the 0–1 cm soil sample had an increase in particles >250 μm and a decrease in particles in the ranges 75–210 μm and <2 μm. These differences between the samples are very likely to be due to the wind erosion at the site since the last cultivation (some 20 weeks). It is possible that some settling of fines could have occurred as a result of the cultivation, but it is unlikely that this process alone could produce the significant particle-size change evident in Figure 5. Furthermore, the particle-size ranges that decreased in the soil correspond to the enriched suspended sediments (Figure 3). Therefore, finer particles are being winnowed from the soil and transported beyond the paddock boundary. This enrichment of the dust is caused by the release of fines from the surface during the erosion process.

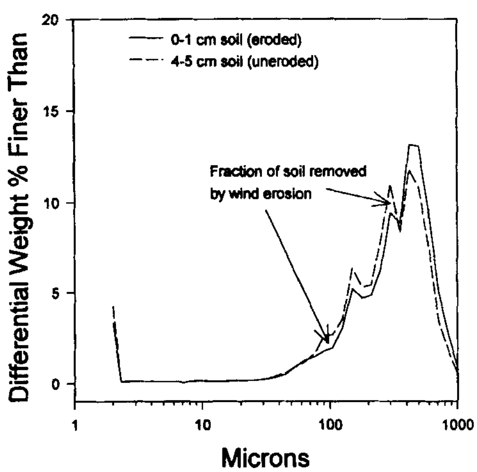

Figure 5. Particle-size distribution of a homogeneous soil after exposure to wind erosion at two depths (0–1 and 4–5 cm) showing the fraction of soil removed by wind erosion over a 20 week period at Mendook

Clay and silt material is sandblasted from the soil surface by saltating particles (Gillette and Walker, 1977). In this way, not only are loose fines removed from the soil, but also those that are bonded to the surface of the quartz grains are blasted off during saltation. This was also observed in wind tunnel studies by Shao *et al.* (1993a) using the same soil as occurs at Mendook. The process is more fully described by Gillette and Walker (1977) who undertook scanning electron microscope studies of both airborne particles and the parent soil, and report that the clay material was similar for both.

Relationship between the soil and eroded sediments. As mentioned previously, the soil at Mendook is from a relict dune field that was probably formed during the last arid phase (18 000 BP). The soil PSD, in part, reflects the aeolian origin of this soil. There is a relatively fine sandy mode, at 420 μm, which represents the lag deposit after the dune-building phase. There is only a limited amount of silt (2–20 μm) left in the soil, as this particle-size range was preferentially removed from the parent sediments during the formation of the dunes. There is a small clay content, which may be either the residual clay from the parent soil or from more recent aeolian dust deposition. The past erosional history has a great influence on the fractions of soil that can now be eroded, and will be discussed in detail below.

Using the detailed particle-size analysis with 38 size classes, it is possible to identify the modes in the soil and eroded sediments at Mendook. These are shown in Figure 3. The primary mode of the parent soil is 420 μm, with minor modes at 300 and 150 μm. The primary modes of the eroded sediments become finer with height. The modes are 250 μm at 0·07 m, 125 μm at 0·12 m, 90 μm at 0·25 and 0·5 m, then remain constant at 75 μm for 1, 1·5 and 2 m. This compares favourably with the PSDs reported by Gillette and Walker (1977) for a sandy soil in Texas (their soil I).

In agreement with Gillette (1977), the eroded sediments that are travelling in saltation at Mendook strongly reflect the sediments from which they were derived. This is evident in the primary modes of the samples from 0·07 and 0·12 cm height. For the 0·07 m sediment sample, the 250 μm mode reflects the 300 μm minor mode in the parent soil. Similarly, the 0·12 m sediment sample mode at 125 μm reflects the 150 μm minor mode in the parent soil.

The recurrence of modes occurs even for the minor modes of the eroded sediments. There is a 90 μm mode in the $z = 0{\cdot}07, 0{\cdot}12, 0{\cdot}25$ and 0·5 m sediments that increases in proportion with increasing height. At $z \geqslant 1$ m, the 90 μm material is present as a 'shoulder' in the PSD, suggesting its importance as a major constituent of the material being eroded from the paddock. The 90 μm mode is reflected in the parent soil PSD as a shoulder in the distribution (Figure 3), and is a size class that is being preferentially winnowed from the soil. Only modes that are present in the parent soil tend to be present in the eroded sediments. This includes both the saltation and suspended fractions.

At Mendook, and at sites described by Gillette and Walker (1977) and Nickling (1983), it is apparent that the parent soil exerts a strong influence over the PSD of the eroded sediments up to 1 m. Gillette and Walker (1977) studied a unimodal sandy soil in Texas (soil I). They used a membrane filter connected to a pump to sample the finer suspended sediments, and a modified Bagnold catcher for coarser sediments. Particle-size analysis (PSA) for finer material was undertaken by automated image scanning, and PSA for the larger particles was undertaken with a sonic sifter system that separated the sample into six classes. The primary mode of the parent soil in Texas was 125–250 μm. The primary mode for the suspended sediment at $z = 1$ m was 75–125 μm, which was present at a secondary mode in the parent soil. The suspended sediment at Texas also had a second mode at 2–20 μm. While this is not represented in the parent soil distribution, it must have been present in very small quantities. This 2–20 μm mode was not present in our more detailed analysis of the Mendook soil and its sediments because it had most probably been removed during the past dune-building phase. Its presence in Texas reflects the difference in the parent material that the sediments were derived from.

This effect of parent material upon sediment particle size is highlighted by a comparison with Nickling's (1983) study. The parent soil Nickling worked on was much finer than the two previously described soils. The Slims Valley soil is a fluvial deposit and has the greatest proportion of its sediment in the <90 μm fraction. Nickling (1983) used a cellulose filter connected to a pump to collect the samples at various heights. PSA was performed on the soils using dry and wet sieving methods, and an image analysis system that gave ten size classes was used on the smaller suspended samples. Nickling's soil from the Slims River was bimodal with

modes at 22 and 63 μm. This silty soil has little to no clay and had less than 5 per cent of the particle mass >250 μm.

The primary mode of the Slims River suspended sediments is 53 μm, which is considerably finer than those from Texas (75 μm) (Gillette and Walker, 1977) and Mendook (75 μm). The Slims River suspended sediment mode (53 μm) reflects the dominance of the parent soil with fine sand and silt material. This material was preferentially winnowed from the soil because of its low threshold friction velocity (Bagnold 1941, p. 88) and enriched the suspended sediment fraction because its low settling velocity allowed it to remain aloft.

Particle size of saltation sediments. For Mendook, it appears that 90 μm is the approximate dividing line between saltation and suspension material. The saltation zone is that <0·25 m height based on the dominance of sediment >90 μm. Above 0·25 m, the PSD is dominated by particles <90 μm. To make the Mendook data comparable to that of Nickling (1983), the PSDs of all samplers $\leqslant$1 m were averaged, which resulted in a mode of 90 μm. Nickling (1983) used a Bagnold-type sediment trap, similar to that described by Gillette and Goodwin (1974), to collect saltation sediments from 0 to 1 m. For the Slims River soil, he reports that the saltation material had a mode of 75 μm, which is marginally finer than was found for Mendook (90 μm). This similarity is expected because saltating particles, regardless of site, have $w_f > w'$, and provided both particle density and w' are similar, then the particle size should also be similar.

This can be further supported by comparison with results from Gillette and Walker (1977). They report a mode of 125–250 μm for saltation sediments collected at 0 to 0·03 m. This compares favourably with the 250 μm mode for sediments collected at 0·07 m at Mendook.

For sampler heights <1 m, there is no clear distinction between sediments moving by saltation or suspension. As Nickling (1983) reports, there is a continuum between true saltation and true suspension, which remains until sufficient height is achieved. At Mendook, heights >1 m had material whose mode was of suspension size.

Sediment flux

Sediment flux (Q) varied from week to week depending on climatic conditions. Data for eight weeks are presented in Table II and cover the range of erosion events over the 22 weeks of the study. Q was calculated between the limits $z_0 = 0{\cdot}001$ and up to a height (z) of 2·3 m using Equation 4

$$Q = \frac{1}{\Delta T \Delta Y \Delta Z} \int_{0{\cdot}001}^{2{\cdot}3} m \mathrm{d}z \tag{4}$$

where m = mass caught in trap in time ΔT; ΔY = trap width = 20 mm; ΔZ = trap height = 50 mm.

Table II. Average wind erosivity (u_e), duration ($u_2 > 7\,\mathrm{m\,s^{-1}}$) and direction of erosive winds ($u > 7\,\mathrm{m\,s^{-1}}$) for eight weeks beginning 21 October 1990 at Mendook. Average sediment flux (Q) and total sediment flux (Q) passing the tower for the week

Day month	Q ($\mathrm{g\,m^{-1}\,s^{-1}}$)	Q ($\mathrm{kg\,m^{-1}\,wk^{-1}}$)	u_e ($\mathrm{m^3\,s^{-3}}$)	Duration (h)	Direction (deg)
21/10	0·0434	26·231	2·92	42·6	260
29/10	0·0052	3·153	2·04	11·6	236
5/11	0·1136	68·714	0·55	12·4	250
12/11	0·3535	213·773	3·62	29·4	201
10/12	0·0220	15·185	1·70	34·2	221
24/12	0·0012	0·729	0·36	16·6	203
31/12	0·0007	0·453	0·59	11·2	249
21/01	0·0002	0·112	0·06	2·0	203

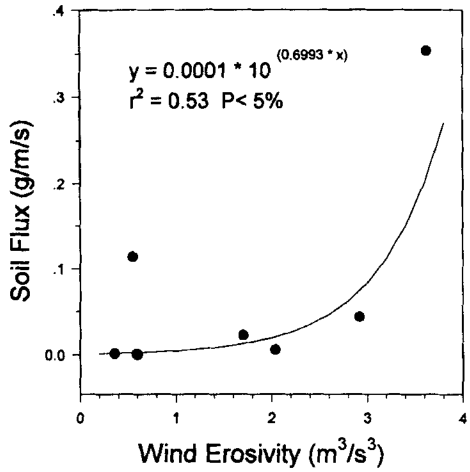

Figure 6. Relationship between wind erosivity (u_e) and average sediment flux (Q) for data for eight weeks from Mendook

Relationship of sediment flux to wind erosivity and duration

Saltation is strongly related to the friction velocity u_* (Bagnold, 1941), which has been used successfully by Gillette and Walker (1977) and Nickling (1978) to predict saltation rates. Nickling (1978) reported that suspension flux was better described by air turbulence and found the stability ratio to be a better predictor of flux rates. Such comparisons are beyond the scope of this paper but will be addressed in future papers. As a first approximation in this study, wind erosivity (u_e) is used as a predictor of horizontal flux rates.

Wind erosivity varied throughout the study period and was estimated from wind speed (u_z) measured at $z = 2\,\mathrm{m}$, using the form $(u_2 - u_t)^3$ where $u_t = 7\,\mathrm{m\,s^{-1}}$ for the threshold velocity (Table II). The threshold wind speed was determined by field observations. The dominant erosive winds ($u_2 \geqslant 7\,\mathrm{m\,s^{-1}}$) were from the southwest quarter (Table II) and were associated with the passage of cold frontal weather systems that cross southeastern Australia. These frontal weather systems are characterized by increasing wind speeds from the northwest that precede strong southwesterly winds in the front as it passes through (Raupach *et al.*, 1994).

There is a positive correlation between the logarithm of Q and wind erosivity (u_e) ($r^2 = 0{\cdot}53$, $P < 0{\cdot}05$) (Figure 6). The regression was strongly influenced by data from 5 November 1990. The data from this weekly observation had a Cook's D statistic of 0·63 which indicates that it had a strong influence on the regression. Removal of this point from the regression increased the r^2 to 0·92 ($P < 0{\cdot}001$). No valid reason can be given for the exclusion of this data point but it highlights the need for a larger data set.

Duration of erosive winds ($>7\,\mathrm{m\,s^{-1}}$ at 2 m height) also had a positive log-linear relation to Q ($r^2 = 0{\cdot}42$, $P < 0{\cdot}10$) but explained slightly less variation in sediment flux than u_e.

Paddock sediment flux estimates

Using the sediment flux data, it is possible to estimate the total sediment flux Q for the 22 weeks of monitoring. This was done by summing the horizontal mass fluxes for each weekly period which gave a Q of $343\,\mathrm{kg\,m^{-1}}$ width. Ninety-five per cent of the erosion ($327\,\mathrm{kg\,m^{-1}}$) took place in five weeks (see Table II), for 21/10, 29/10, 5/11, 12/11 and 10/12). The duration of erosive winds $>7\,\mathrm{m\,s^{-1}}$, for the five weeks in which most of the erosion occurred, was 130·2 h. The total duration of monitoring was 3696 h indicating that 95 per cent of the erosion occurred in 3·5 per cent of the time.

The sediment flux can be considered as soil loss from a paddock if the flux rate remains constant to the boundary of the paddock and all the saltation and the suspension material leave the paddock on the down-wind side. In the case of Mendook, the saltation material did not leave the paddock because the saltation material would flow from the sandy dune rise onto the much more cloddy surface of the adjacent

non-eroding dune swale. However, the suspended sediments would continue to be carried aloft over the swale and out of the paddock.

If we assume that the sediments <90 μm are carried aloft from the paddock, then the dust flux rate, $Q_{<90u}$, up to $z = 2{\cdot}3$ m, can be calculated. Using Equation 2 to predict the mass of material for a range of heights, and Equation 4 to calculate the flux of the sediments <90 μm, gives $Q_{<90u} = 4{\cdot}2$ kg m^{-1} width for the week of 10 December. The Q for this weekly sampling period was 15·2 kg m^{-1} width (Table II) and the $Q_{<90u}$ was 4·2 kg m^{-1} width which represents 27 per cent of Q. This indicates that a significant mass of soil is leaving the paddock.

The topsoil (0–1 cm) from which the dust was derived has 11·3 per cent <90 μm. In comparison, the dust was 2·3 times enriched with <90 μm material, highlighting the fact that it is the fines that blow over the fence that should be of concern to farmers and not the saltation material piled up against the fence.

CONCLUSIONS

This study, on a cultivated paddock at Mendook, provides the following conclusions.

- The distribution of sediment mass (m) with height (z) is best described by a log–log distribution ($r^2 > 0{\cdot}86$) of the form $m = \alpha z^{-\beta}$. The distribution is highly skewed towards the bed because of the influence of gravity on the coarser fractions. Once the coarser fractions are removed from the analysis, the distribution becomes less skewed. The distribution of sediment mass <90 μm with z was best described by a semi-logarithmic equation ($r^2 = 0{\cdot}99$, $P < 0{\cdot}001$) of the form $m < 90\,\mu m = \alpha - \beta \log z$. This distribution is less skewed because the finer particles are less under the influence of gravity and more under the influence of the vertical velocity component of the wind.
- The particle size distribution (PSD) of the eroded sediments strongly reflects the parent soil. The closer the sediment sample was taken to the bed the greater the similarity in the PSD modes. As height increased, the sorting became more complete and the multimodal PSD of the lower samples ($z < 1$ m) gave way to unimodal distributions. In comparison with other studies in North America, coarser textured soils had suspended sediment modes that were coarser than finer textured soils, because there was no fine material in the parent soil to erode.
- The total sediment flux Q for the 22 weeks of monitoring was 343 kg m^{-1} width. Ninety-five per cent of the erosion (327 kg m^{-1}) took place in 3·5 per cent of the time. Material <90 μm was assumed to be lost from the paddock. The flux rate up to 2·3 m height of this fraction $Q_{<90u}$ was 4·2 kg m^{-1} for one week (10 December 1990). This represented 27 per cent of the total flux for that week and indicates significant enrichment of the suspended sediments.
- Sediment flux was closely related to the wind erosivity which explained 53 per cent of the variation in sediment flux.

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